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(54) Abstract Title
Communication system using mobile repeaters

(57) A radio communication network comprises a plurality of relatively closely spaced-apart mobile stations (MSs), each mobile station MS comprising a transmitter and a receiver, at least some of the mobile stations being arranged to act as controlled repeaters to relay an incoming traffic signal to a nearby mobile station or stations The repeaters are controlled by a central system control SC able to communicate with each mobile station MS. The central control has map data stored therein, or available thereto, providing two-or three-dimensional information on the physical layout and local transmission characteristics of the region in which the mobile stations are located, and is arranged to utilise information gained by monitoring the power required to perform a signal exchange (handshake) between adjacent mobile stations MSs and information from the map data, to provide an estimate of the actual positions of the mobile stations MSs.

In Figure 4 fixed station FS_1 is able to handshake with MS_1, MS_2 and MS_3 and these MSs have been able to handshake with MS_4, MS_5, MS_6 and MS_7.

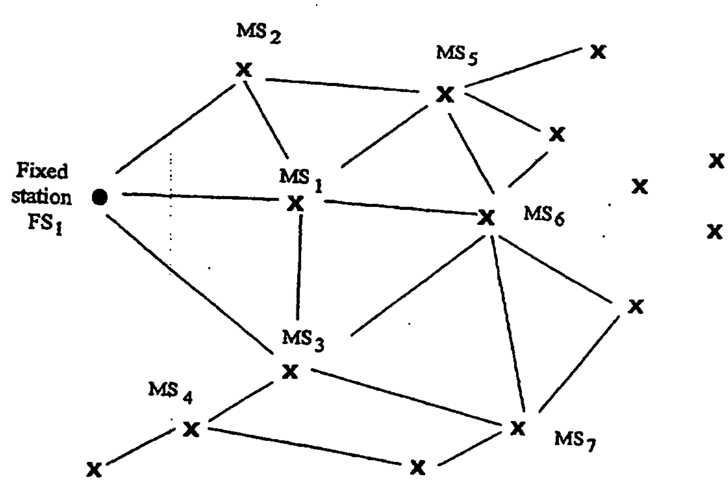

Figure 4

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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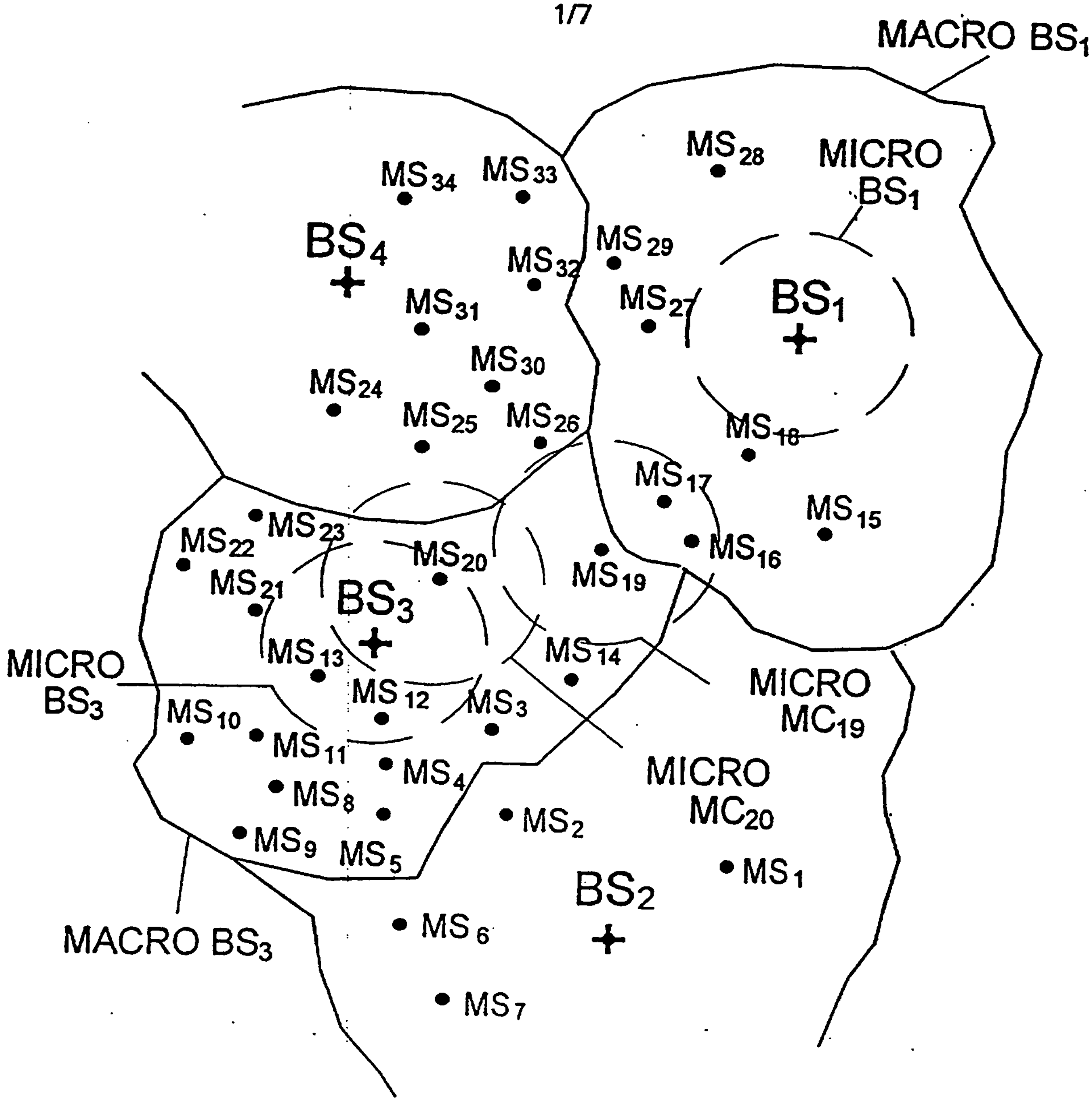

PRIOR ART

Figure 1

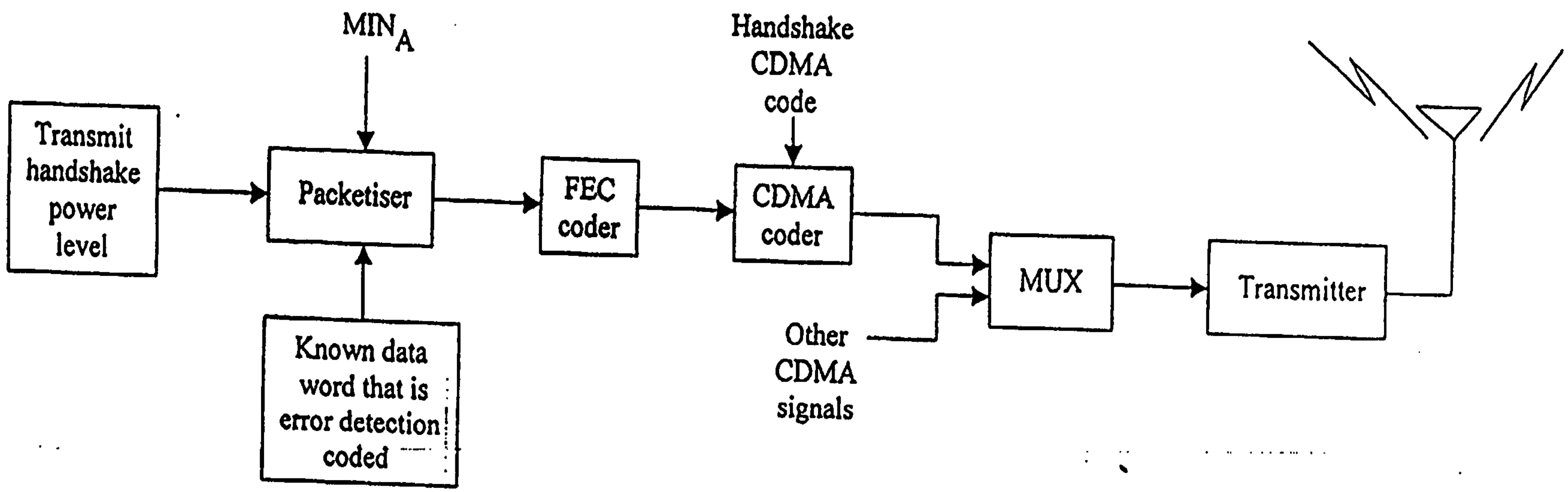
MIN_A
Transmit handshake power level
Packetiser
FEC coder
Handshake CDMA code
CDMA coder
Known data word that is error detection coded
Other CDMA signals
MUX
Transmitter

Figure 2

(b)

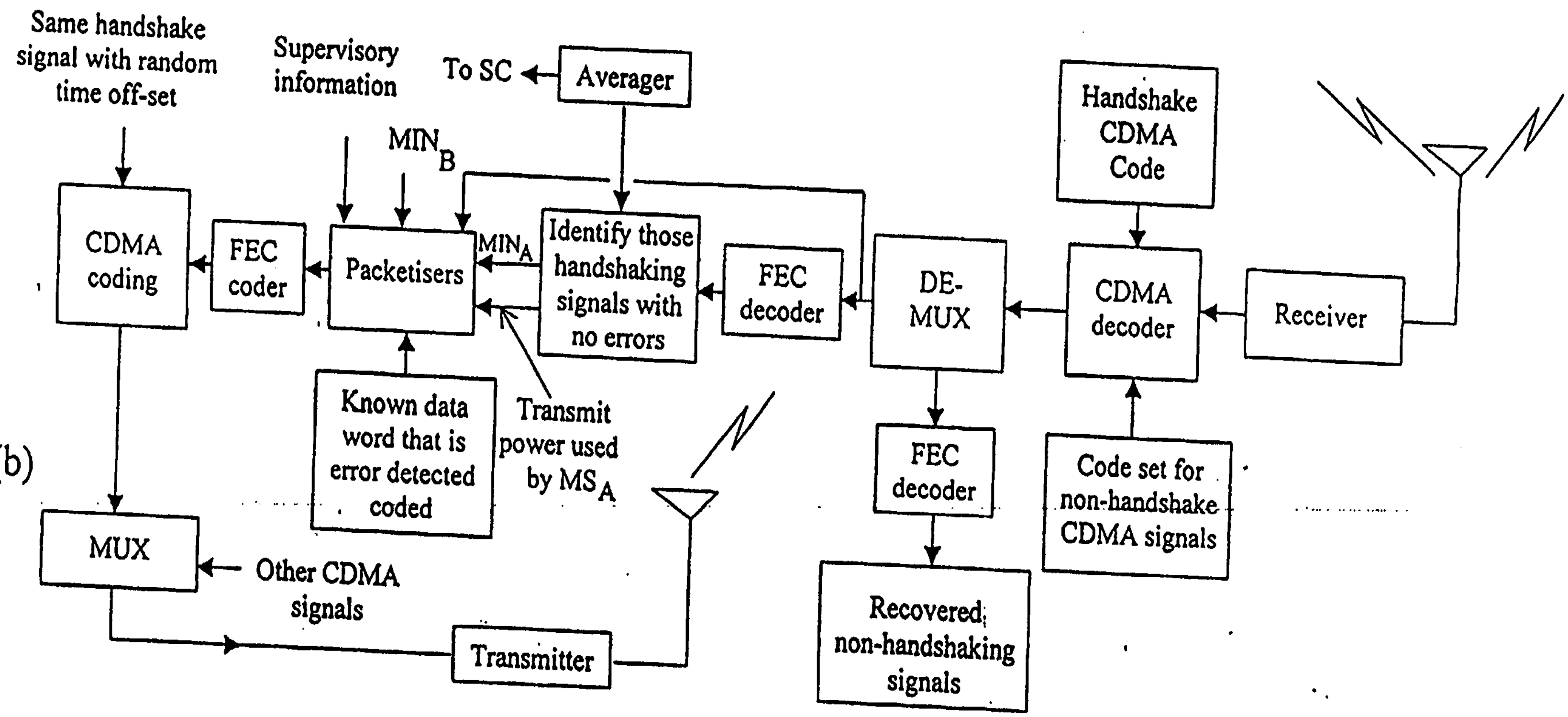
Same handshake signal with random time off-set
Supervisory information
To SC
Averager
MIN$_B$
MIN$_A$
CDMA coding
FEC coder
Packetisers
Identify those handshaking signals with no errors
FEC decoder
DE-MUX
CDMA decoder
Receiver
Handshake CDMA Code
Known data word that is error detected coded
Transmit power used by MS$_A$
FEC decoder
Code set for non-handshake CDMA signals
MUX
Other CDMA signals
Transmitter
Recovered non-handshaking signals

Figure 3

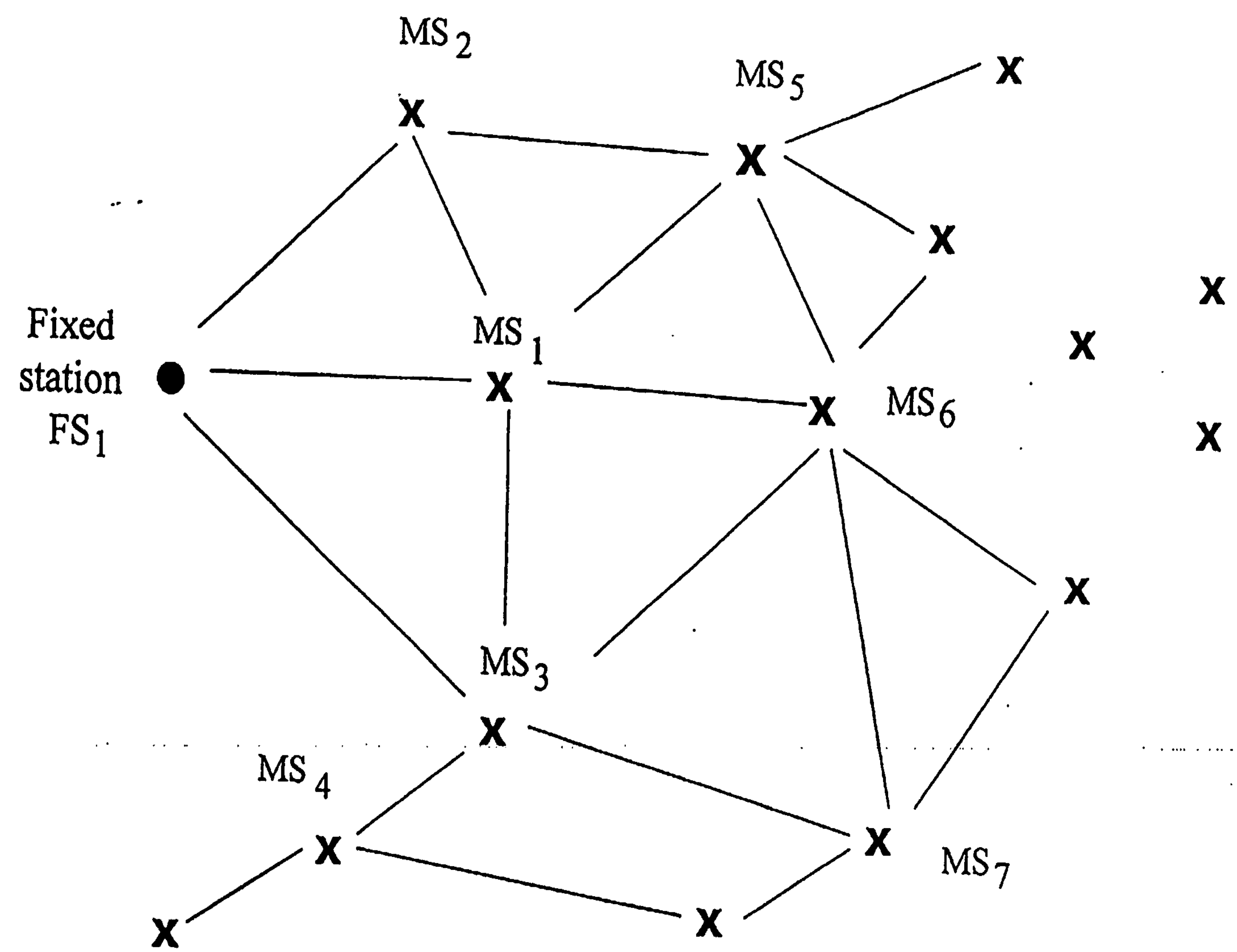

Figure 4

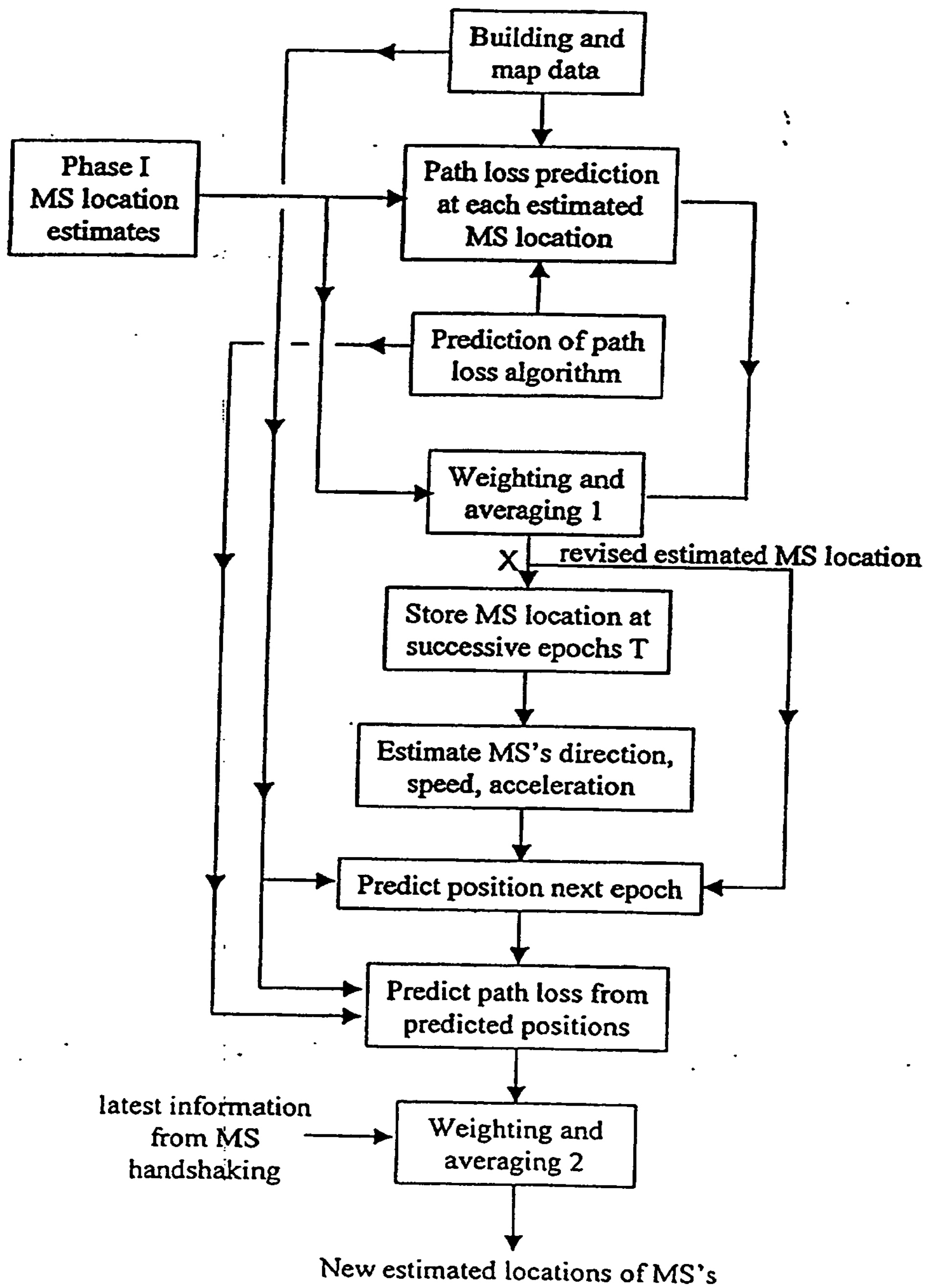
Building and map data
Phase I MS location estimates
Path loss prediction at each estimated MS location
Prediction of path loss algorithm
Weighting and averaging 1
X
revised estimated MS location
Store MS location at successive epochs T
Estimate MS's direction, speed, acceleration
Predict position next epoch
Predict path loss from predicted positions
latest information from MS handshaking
Weighting and averaging 2
New estimated locations of MS's

Figure 5

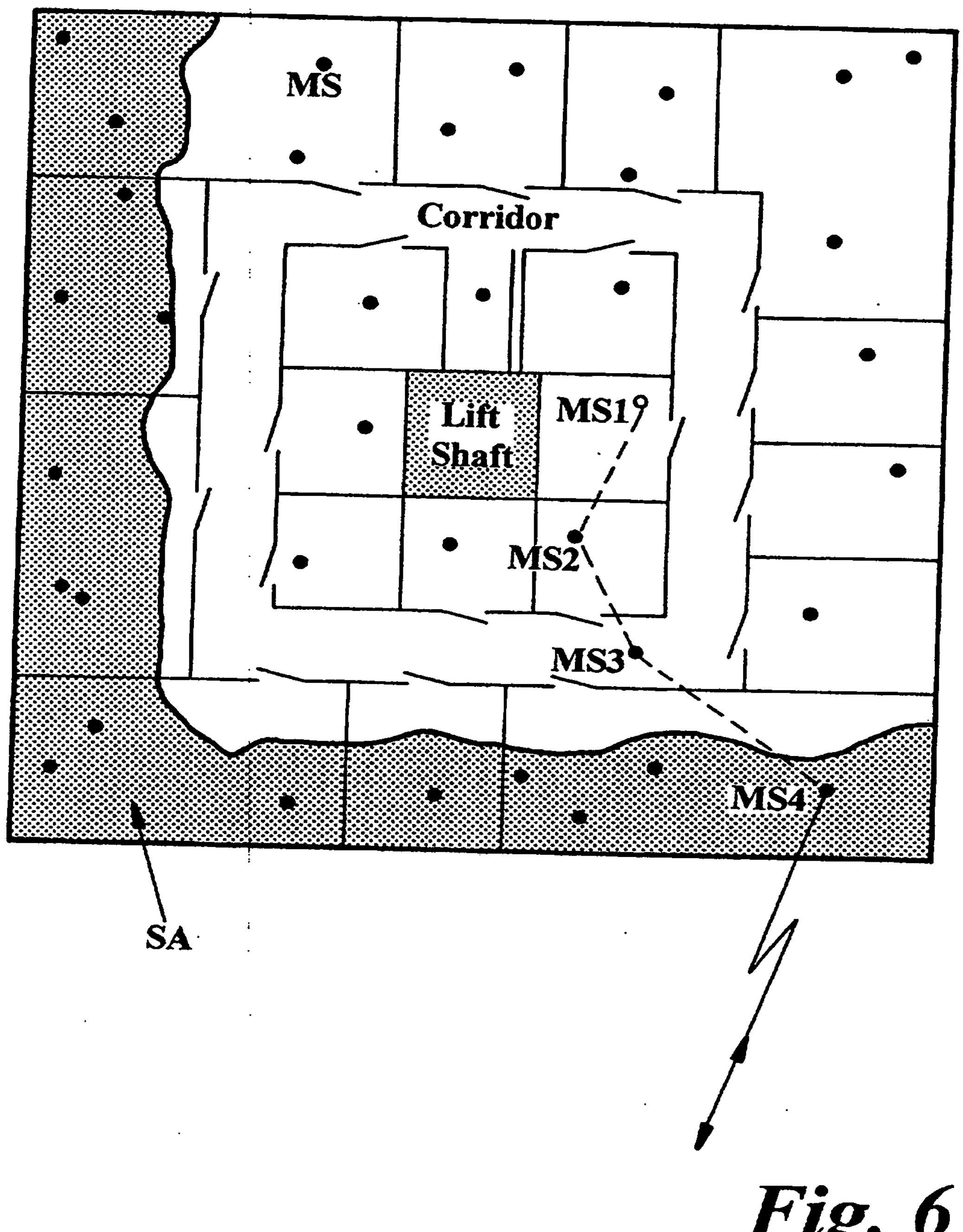

Fig. 6

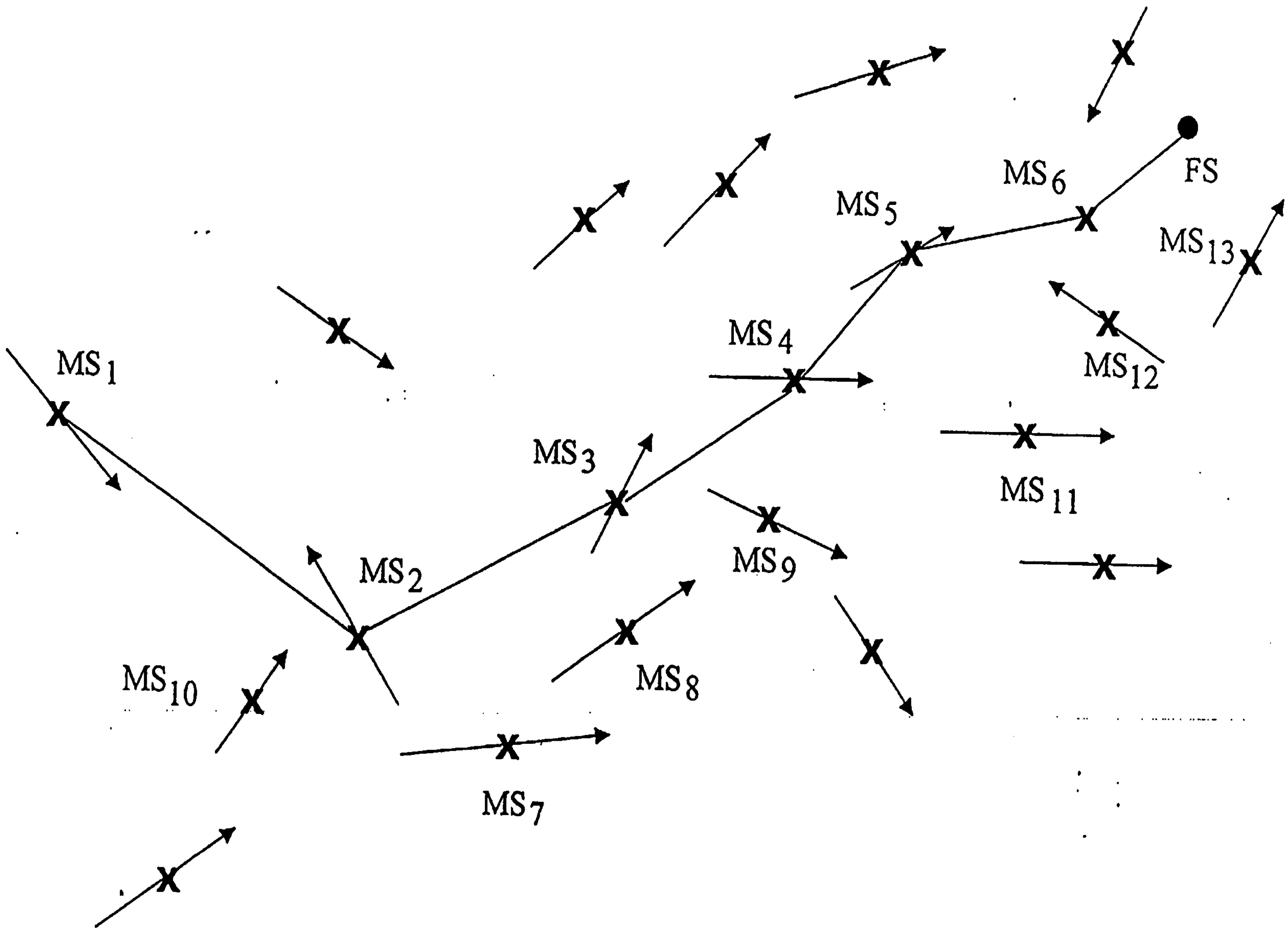

Figure 7

COMMUNICATION SYSTEMS

This invention relates to communication systems and particularly, but not exclusively, to cellular telecommunications systems.

This invention relates to inventive modifications and improvements to the communication systems set forth in our earlier patent application no. GB 9711533.1 filed 5 June 1997 (publication no. GB 2326059). That application will hereinafter be referred to as the 'prior application'.

The disclosure of the prior application is hereby incorporated into the present application, but for convenience various features of the invention of the prior application will first be repeated.

In order to increase the capacity in cellular networks it is common practice to decrease the cell size and thereby increase the re-use of radio channels.

Small cell size means more base stations (BSs) are required. This means that more cell sites are needed to locate the BSs, and the cell sites must be connected in some fashion to the network. It may be that the BSs are arranged in a local area network by connecting them using radio or optical fibre. The local area network (LAN) may then be connected to other LANs and thence to the network switches and databases.

At the first level of deployment of microcells it is evident that there is a need for a plurality of BSs, cell sites, and the interconnection of the BSs to each other or directly to the next stage of the network.

We consider that BSs and interconnection cost of materials are likely to decrease substantially as the deployment of microcellular networks

continues. However, labour costs are likely to rise in line with any inflation. This is also probable with site acquisition costs for base stations. Methods are therefore required to decrease infrastructure costs associated with high capacity small cell networks.

Prior Art Solution

Macrocellular sites create cells larger than microcells. A popular concept was to have a network of microcells overlaid by a macrocellular network, such that one macrocell may overlay more than one microcell, and possibly clusters of microcells. The macrocells may be used to cover radio dead-spots in the microcellular network, or to assist in handovers (HOs) when there is a shortage of microcellular channels due to them being busy at the time of handover requests.

We mean by microcell a small cell relative to a macrocell. The microcell may be provided for users at street level, or at a higher level. In the latter case we are considering three dimensional microcells, as exemplified by a microcell composed of a few floors in a tower block of flats or offices.

Summaries of the Invention of our prior application

According to one aspect of the invention of the prior application, a communication network comprises at least two base stations located in fixed relatively widely spaced-apart positions, a plurality of relatively closely spaced-apart mobile stations in the space around the two or more base stations, the base stations each comprising base station radio transmitter means and base station radio receiver means, the mobile stations each comprising mobile station radio transmitter means and mobile station radio receiver means, at least some of the mobile stations

being arranged to act as controlled repeaters to relay an incoming traffic signal at a mobile station to a nearby mobile station, the repeaters being controlled by a network control means, repeater control signals from the control means to the mobile stations and ancillary control information signals from the mobile stations to the control means being transmitted from or to one or more control signal stations as radio signals on relatively long radio transmission paths as compared with the relatively short distances between the mobile stations.

The relatively short path lengths between the mobile stations allows the known advantages of small cells to be realised in permitting a heavy utilisation of the available wavebands by traffic signals when the mobile stations are operated at relatively low powers for this purpose, but relatively long path lengths can be accommodated for the control signals since the control signals need only convey a relatively small volume of data as compared with the traffic data.

This means that in most applications of the invention of the prior application relatively few control signal stations need be employed. When the control signal stations are land-based stations this has the advantage that a relatively small number of sites need be acquired for the fixed stations.

The control signal stations may be provided by one or more satellites or aerial stations, in which case the repeating mobile stations are preferably each provided with a suitable signal receiver to receive repeater control signals transmitted from the satellite or aerial station and a suitable signal transmitter to transmit ancillary control signals to the satellite or aerial station.

Aerial stations are sometimes referred to as high altitude platforms. They differ from satellites in that they are very much closer to the earth's surface, say 5 to 36 km, usually unmanned, and held on station. They have multiple beam antennas for creating terrestrial radio cells.

Preferably the mobile stations are so arranged as to exchange signals (make handshakes) with the nearest one or more mobile stations in order to establish the relative positions of the mobile stations, and preferably the power required to perform the handshake is monitored, and this information is transmitted by the mobile stations to the control signal stations, that is using the control signal network.

The combination of mobile station positional information and information on the quality or integrity of the available individual links between mobile stations provided to the system control, enables the system control to select the preferred route or routes for relaying traffic signals. For high bit rate traffic signals a combination of a plurality of routes may be selected.

According to a second aspect of the invention of the prior application a communication network comprises a plurality of base stations located in fixed spaced-apart positions, a plurality of mobile stations in the region between the base stations, the base stations each comprising base station radio transmitter means for transmitting signals, and base station radio receiver means for receiving signals, the mobile stations each comprising mobile station radio transmitter means for transmitting signals, and mobile station radio receiver means for receiving signals, at least some of the mobile stations being arranged to act as a controlled repeater to relay an incoming traffic signal to a nearby mobile station, or base station when nearby, the relay action being controlled by a network control means which communicates with the mobile stations by way of the base

stations to provide relay action control signals, the signal strength of the mobile station transmitter means when transmitting traffic signals being such as to define a mobile station microcell having a transverse dimension which is generally substantially less than the spacing of the base stations, the base station transmitter means when acting to communicate traffic signals with an adjacent mobile station having a signal strength such as to define a microcell of dimensions comparable with the dimensions of the mobile station microcells, but the base station transmitter means when acting to provide said relay action control signals to the mobile stations having a signal strength sufficient to define a macrocell for control action of dimensions comparable to the spacing between the base stations.

Thus by using the mobile stations to act as repeaters for relaying traffic signals from one mobile station to another mobile station, or to a nearby base station, we avoided the need for a network of closely-spaced base stations. Furthermore we provided centralised control of the virtual path by which the traffic signals flow from mobile station to mobile station and onward before arriving at a base station.

The control means can communicate with the base stations by any convenient communication link. This can be a land line of any kind or it may be a radio link. In the case of a radio link the base station transmitter means and base station receiver means can form part of this link.

The base station transmitter means, when acting to communicate traffic signals with reduced signal strength compared to the usual signal strength required in conventional macrocells, minimises the interference to the traffic channels of other base station receiver means such that, in the

limit, frequencies for traffic use may be allocated with a re-use of unity, thus significantly increasing the capacity of the network.

Discussion of The Present Invention

A first aspect of the present invention is concerned with a system in which mobile stations (MSs) act as repeaters for relaying traffic signals, and with an improved means for determining the choice of virtual path between the two base stations (BSs).

In the prior application the power required to perform handshakes between adjacent MSs was monitored, and this was used to estimate the *relative* positions of the MSs. The procedure was repeated at regular intervals to compute a fresh estimate of the relative positions of the MSs.

We have now devised a system which can provide an estimate of the *actual* positions and movement of the MSs.

According to the first aspect of the present invention a radio communication network comprises a plurality of relatively closely spaced-apart mobile stations, each mobile station comprising mobile station radio transmitter means and mobile station radio receiver means, at least some of the mobile stations being arranged to act as controlled repeaters to relay an incoming traffic signal to a nearby mobile station or mobile stations, and being controlled by a central system control means SC able to communicate with each mobile station, characterised in that the central system control means has map data stored therein, or available thereto, the map data providing two-dimensional, or three-dimensional, information on the physical layout and local transmission characteristics of the region in which the mobile stations are located, the central control means being so arranged as to utilise information gained by monitoring

the power required to perform a signal exchange (handshake) between adjacent MSs and information from the map data, to provide an estimate of the actual positions of the MSs.

A preferred embodiment of a network in accordance with the first aspect of the present invention operates as follows. Each MS exchanges signals at relatively low power with other MSs which are in close proximity, notes the transmitted and received signal power used in these exchanges, obtains from the neighbouring MSs their identities, performs these procedures periodically, and signals at high power to the fixed BS sites in the network a report on the transmitted and received powers used in the exchanges with neighbouring MSs as well as the identities of these MSs. The fixed BS sites convey this information to system control (SC).

Initially SC uses only the identities of the MSs in the reports, and estimates the position of the MSs that are so close to a BS that in making the signalling exchanges they not only interacted with other MSs, but also with a BS. Next the locations of the MSs that exchanged signals with the MSs close to the BS, but not with the BS, are estimated based on their identities, and then the location of the MSs a little further away are considered until an estimate of substantially all MS positions are formed. These locations are made substantially exclusively on the identity information of the report.

SC now employs algorithms of the kind that are used in radio planning tools for siting BSs. These algorithms require access to map data of terrain and man-made features, eg buildings, that may have a significant effect on radio propagation. A site is selected for a BS, and an algorithm computes the path losses from the site as a function of distance in all directions.

In accordance with the present invention instead of computing these path loss profiles for BSs, we utilise such algorithms to compute them for each MS, and at each epoch, *T*.

SC already has an estimate of each MS's position. Using these positions, SC uses the radio planning tool algorithm to predict the path losses in all directions around each MS. Each MS has provided SC with a set of its transmitted and received levels used in its exchanges with neighbouring MSs. From these reports SC has a set of measured path loss values from each MS to its neighbours.

For each MS, SC re-estimates the positions of the neighbouring MSs such that the measured path loss values, and the predicted path loss values that are a function of map data, coincide.

Notice that there may not be one unique position for each MS and consequently SC may have a cluster of possible locations for each MS. The final estimate can be made by various forms of weighting procedures, of which the simplest is taking the average of all the estimates of positions for a given MS. This complex process must be done at every epoch, *T*, (unless SC thinks the MSs are basically stationary).

All MSs report their interactions to SC periodically and SC continues to up-date its location estimates at the periodic rate. After this has been done a number of times, SC computes not only the position of each MS, but preferably estimates their direction of travel, speed and acceleration. Predictions are now made of where the MSs will be at the next epoch, and path loss predictions are made using the planning tool from these predicted positions when the MSs next report. SC is now able to refine its estimates of the locations of the positions of the MSs.

Because SC is able to compute the direction, speed and acceleration of each MS it is able to decide if a MS will need to be excluded or included in a virtual path that is conveying traffic. Hence maintaining the flow of traffic from and to a fixed BS site to a MS via a virtual path composed of moving MSs is enhanced. The procedure also enables SC to continually anticipate establishing a virtual path for any MS, and even multiple paths for any MS should this MS require or need multiple paths for the conveyance of its traffic. Re-routing of virtual paths, their maintenance, and anticipation of virtual paths that may be required, can all be done by the above procedures.

A second aspect of the present invention is concerned with providing control signals to 'hidden' MSs, that is MSs that are located in locations partially enclosed by objects having relatively poor signal transmission characteristics.

According to the second aspect of the present invention a radio communication network comprises a plurality of relatively closely spaced-apart mobile stations, each mobile station comprising mobile station radio transmitter means and mobile station radio receiver means, at least some of the mobile stations being arranged to act as controlled repeaters to relay an incoming traffic signal to a nearby mobile station or mobile stations, and being controlled by a central control means able to communicate with each mobile station, characterised in that the central control means is so arranged as to identify any 'hidden' MSs with which the central control means cannot directly signal due to excessively high path loss values and/or interference levels, and to identify any MS positioned adjacent to the hidden MS, which may be termed for convenience a 'distributing MS' (DMS), in a position so as to be capable of communicating with the hidden MS, the central control means then

providing signals to the hidden MS by way of the distributing MS (DMS).

When the hidden MS is itself being used to relay signals to another hidden MS then the signals passed by way of the DMS can be control signals.

Thus SC is able to establish and modify virtual paths involving MSs, referred to here as hidden MSs, with whom it cannot directly signal to because of excessively high path loss values or excessive interference levels, provided there is one or more MSs, referred to here as a distributing MS (DMS), which can signal at high power to a fixed BS site.

SC instructs a DMS how to establish virtual paths with the hidden MSs. The hidden MSs behave in the same manner as other MSs in that they communicate with neighbouring hidden MSs, and so forth, but they must establish a virtual path to a DMS. This is achieved by performing the handshaking operations at every system epoch as previously described, but this time the hidden MSs (HMSs) compute the path losses and send them to other HMSs within their locality these path loss values and the identities of the MSs associated with them. The HMSs also pass on the information gained of HMS identities and path losses of other MSs with whom they did not handshake. Soon each HMS and their DMS know of all the HMSs and the path losses between them. DMS signals this information at every system epoch (as the HMSs may be moving) enabling SC to decide on suitable virtual paths for any HMS.

Once SC learns of these hidden MSs preferably it decides to maintain the virtual path or create new ones via the DMS.

Preferably, armed with a three-dimensional radio planning tool, SC is able to utilise reports from DMSs on the received signal levels from beacon signals transmitted from the fixed BS sites, or on the received signalling levels from fixed BS sites if they are transmitted at a constant power, to deduce where the DMSs are located. Reports from the DMSs enable SC to predict where the hidden MSs are located. By these means, SC is able to locate the position of a hidden MS, for example within a building or airport.

Some communications systems in accordance with the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is Figure 1 of the prior application GB 9711533.1;

Figure 2 is a block diagram of part of the transmission system of a mobile station MS_A;

Figure 3 is a block diagram of part of the transceiving system of a mobile station MS_B which is near to the mobile station MS_A;

Figure 4 shows a distribution of mobile stations which are near to a fixed station;

Figure 5 shows a flow diagram of the algorithm used to obtain improved estimations of the mobile station locations;

Figure 6 is a plan of a floor of a multi-storey building; and

Figure 7 illustrates a virtual path between mobile station MS_t and a fixed station FS using mobile stations as repeaters.

We shall firstly describe the operation of a system in accordance with the first aspect of the present invention which is concerned with estimating actual positions of the mobile stations (MS's). The physical disposition of the elements of the system can conveniently be that shown in Figure 1 of the prior application.

Each mobile station (MS) in the ad hoc network is instructed by system control (SC) to periodically identify the MSs within its locality. Accordingly, each MS transmits a short signal to any MS that may be within its locality and requests that any MSs that have received its signal should respond. In sending out its requests for a response, a MS identifies itself and the power level of its transmission. Each MS is given permission by SC to ratchet-up its transmission power in a series of steps until either the transmission power reaches an assigned maximum value set by SC, or a response from M MSs is received, where M is a system parameter. Should the maximum power from a MS fail to illicit a response from another MS, SC knows that currently this MS cannot be used to establish a virtual path for the conveyance of other MSs' traffic signals, and that its traffic signals must be conveyed directly to a fixed BS site, such as BS_1 of Figure 1 of the prior application. However, if one to M MSs respond to a particular MS then this MS reports both the identities of the responding MSs, and the transmitted and received signal levels used in the communications with each of the one to M responding MSs. Rather than ratcheting up its power level for handshaking purposes, SC may direct a MS to use a specific power level for handshaking purposes. In either approach, it may be necessary to repeat the process a number of times and to average the received signal levels in order to combat the fading of radio signals that are often a feature in mobile radio communications.

Initially SC builds up the picture of where the MSs are located by first deciding on the positions of the MSs close to each fixed BS (BS1-BS4), then the positions of the MSs a little further away from each BS, and so on until an estimate of the positions of all MSs are established. This initial estimate of MS positions is obtained using the information provided to SC by each MS of the identity of those MSs within its vicinity.

A refinement is now made utilising the path loss estimates between MSs. This stage requires SC to utilise map data stored therein, or available thereto, to estimate the effect of local conditions, eg terrain features, the location, shape and size of buildings, presence of rivers and lakes, details of vegetation, and so on, to predict the path loss values between two MSs, one seeking a response from the other. A radio planning tool algorithm, as previously discussed, may be employed to predict path loss values. SC combines the path loss prediction with its knowledge of the transmission and reception levels used in the communication of each MS with each of the MSs from which a response was obtained, to refine its estimate of a MS's position. Every *T* seconds, SC receives measurement reports from its MSs and estimates the positions of each MS based on path loss predictions. Next, SC introduces the temporal parameters of each MS to identify the speed, acceleration/retardation derived from successive estimates of the position of each MS at each epoch. SC is now able to anticipate where each MS is expected to be at a given epoch, enabling new virtual paths to be anticipated if the MSs supporting a virtual path move in such a way as to cause the reliability of a path to become poor.

The nature of ad hoc networks means that MSs are sufficiently close to each other to support virtual paths for conveying traffic, and are,

generally, closer to other MSs than they are to the fixed site BSs. By involving MSs in the estimates of the positions of the MSs, SC is able to predict their position with greater precision than methods that rely on the much fewer fixed sites to determine the positions of the MSs.

An example of a handshaking procedure between a mobile station, say MS_A, and other mobile stations within the range of the maximum handshaking transmission power prescribed by system control (SC) to MS_A, will now be described for code division multiple access. MS_A formulates a handshaking packet consisting of the mobile identity number of MS_A, namely MIN_A, the transmitted power level to be used in transmitting the packet, a known data word that has been error detection coded (an optional extra) and other supervisory information that SC considers to be required. Forward error correction (FEC) coding of the packet data will usually be deployed.

Figure 2 shows the relevant handshaking block schematic of the transmission system for MS_A, and Figure 3 the transceiving system of a nearby mobile station MS_B. The transmission power level of the handshaking signal from MS_A is prescribed by SC but is usually sufficient to create the coverage of a small cell, for example, a microcell. SC makes available a CDMA code for handshaking purposes that is known to all MSs. The handshaking code CDMA codes the handshaking packet, which is multiplexed (MUX) with other CDMA signals and transmitted.

The MS_B receiver uses its handshaking code to determine if one or more MSs are attempting to handshake with it. MS_B also CDMA decodes other signals with which it is communicating. The handshake signals are separated from the other signals in the demultiplexer (DE-MUX). Once the handshake signals whose error detecting codes indicate that they have been received with a low probability of error have been identified, the

MIN_A for MS_A and the transmitter power information sent by MS_A are conveyed to a packetiser. To this information is added MIN of MS_B, i.e., MIN_B, an error detecting code, the received signal level of the handshake signal, and any other essential supervisory information. The packet is then FEC coded, and then CDMA coded using the same code as employed by MS_A for handshaking. Other CDMA signals are then multiplexed with this and any other MSs.

Should the signals arrive back at MS_A from MS_B and from other MSs at the same time, they may corrupt each other's signals. When this happens MS_A repeats its transmission and asks the receiving MSs to transmit back to it after a random delay decided by themselves.

Because of fast fading over the radio links MS_A continues to transmit at the same power the handshake packets. The received level of the handshake signal at MS_B, say, may differ with time due to fast fading (and in some circumstances from shadow fading). MS_B averages the values of the received power levels it received from MS_A, and it is this average value that is reported to SC. As the up-link and down-link transmissions may be on different frequencies, MS_B undertakes the same procedures as MS_A. Consequently MS_B is able to inform system control of the average handshake power it needs in order to have an effective link to MS_A.

It will be appreciated however that a synchronised system could be devised that uses specific timeslots for the probing/handshaking process, or particular frequencies could be reserved for this purpose.

The first phase, Phase I, of the initialisation process used by SC to estimate the location of the MSs will now be described. The MSs collect the identities and received signal levels from nearby MSs during an epoch

period of T seconds. This information is signalled to the nearest fixed station (FS). If there are no nearby MSs, the MS cannot participate in an ad hoc network and behaves as in a conventional cellular network. The FSs transmit the information they received from the MSs to SC. Starting with the information from MSs that have received a handshake from a fixed station, SC estimates the relative position of these MSs and the other MSs they have handshaked. This involves the use of the mobile's identity number (MIN) and the computation of the path loss between the MSs to estimate their relative positions. For example, in Figure 4, fixed station FS_1, is able to handshake with MS_1, MS_2 and MS_3, and these MSs have been able to handshake with MS_4, MS_5, MS_6 and MS_7. (In Figure 4 the X symbols signify mobile stations and the straight lines indicate handshake radio links.) SC knows that MS_1, MS_2 and MS_3 are the closest MSs to FS_1, and interprets the path loss between itself and each of their MSs in terms of distance, assuming a simple path loss law. It then repeats the process for MS_1 with MS_5, MS_2, MS_3, MS_5 and MS_6. Then for MSs handshaking with MS_2, followed by those handshaking with MS_3. This completes the first zone. SC now address the handshake results for MS_4, MS_5, MS_6 and MS_7. This method continues moving progressively to MSs further away from the fixed station. Now FS_1 could have the orientation of where the MSs are in the wrong direction, eg FS_1, might assume initially that MS_2, MS_1, MS_3 etc are to the left rather than to the right in Figure 4. However, the same type of process is done for other FSs, and when the MS are considered that are close to the signalling boundaries of the cells created by the FSs, errors in the orientation of where the MSs reside becomes apparent. SC now changes the orientations of MSs relating to each FS until there is reasonable agreement regarding the location of the MSs near the signalling boundaries of each FS (in the light of the signalling information received

by SC from all the FSs). At this junction, phase I of the initial MS location procedure is completed.

Phase II of the initial MS location procedure is described with reference to Figure 5. Phase I MS location estimates are applied to the path loss predictor that provides path loss contours in either two-dimensions or in three-dimensions around each estimated MS location. To achieve this it needs building and terrain map data of the locality as well as a prediction algorithm (for example, of the proprietary type sold by Multiple Access Communications Ltd) and other software support of the type found in proprietary planning tools. Suppose SC has calculated from the handshaking data that MS_A has path loss values of PL_{AB}, PL_{AC}, PL_{AD}, between MS_A and MSs, MS_B, MS_C and MS_D, respectively. The path loss prediction from the location of the MS_A obtained in Phase I may yield $\overline{PL}_{AB}$, $\overline{PL}_{AC}$ and $\overline{PL}_{AD}$ instead of PL_{AB}, PL_{AC} and PL_{AD}, respectively. The weighting and averaging block in Figure 3 may simply average PL_{AB} and $\overline{PL}_{AB}$ to give a new estimate $\hat{PL}_{AB}$. The averaging process may involve weighting in favour of the predictions. Alternatively, the weighting and averaging process may include more predictions of nearby MSs in order to get an improved estimation of each MS location.

The revised MS locations are stored at each epoch T, and armed with a set of locations for each MS its direction, speed and acceleration are easy to compute. For example, the distance a MS travels between epochs will provide estimates of the speed and acceleration of the MS, while the locations will indicate its changing direction. Knowing a MS speed, acceleration and direction, enables SC to predict its location at the next epoch. A prediction of path loss from the predicted location is made. SC does this for each MS, and it also knows at each epoch T of the results of the latest handshaking. Again it does a weighting and

averaging procedure of the type described above. By this means a new set of MS locations is established.

Observe in Figure 5 that Phase II of the initialization process is completed when the revised estimated MS locations are obtained. This is at point X in Figure 5. After this initialization process, the output of the 'weighting and averaging 2' block is connected via a switch (not shown) to point X .

Hidden Mobile Stations

A modification of the system just described will now be described, the modified system being arranged to accommodate, in accordance with the second aspect of the invention, hidden MSs.

In some situations, fixed site BSs may be unable to signal to some MSs when the path loss between the fixed BSs and these MSs is too large to sustain operational communications links. A situation of this type is exemplified when MSs are located in an underground car park, or in the centre of a large building when radio penetration losses into and through the building become too excessive for communications to take place. Provided there is a MS say MSj, that is able to communicate by a virtual path or directly to a fixed BS and thence to SC, and is also able to communicate with a MS, say MSk, whose path loss and/or interference to a fixed BS is too great to sustain radio communications, then SC may allow MSk to form a virtual path to the fixed BS via MSj. All signalling communications and traffic communications between MSk and SC take place via MSj. This concept can be extended to a plurality of MSs that cannot signal directly to a fixed BS, provided virtual paths can be established between these MSs and to one MS that can signal to a fixed BS. The MS are required to increase the transmitted power compared to

what they use in an ad hoc mode every T seconds when they signal to a fixed station (FS). Some MSs, for example those located within buildings, are unable to do this and for this reason we refer to them as hidden MSs as they cannot be directly accessed by a FS. We define a distributing MS (DMS) as a MS which is able to handshake with a hidden MS (HMS) as well as with a FS. HMSs handshake with other HMSs around them in the manner previously described for MSs that are not hidden. However, there is an important difference regarding how this handshaking information is used. Each HMS computes the path loss between it and each HMS or DMS that it handshakes with. This information is passed to every HMS within its locality. Eventually this information of all the HMS in the locality and the path loss values between them arrives at the DMS. This information is updated every T seconds. The DMS send this information to a FS, who relays it to SC, every T seconds. SC is now in a position to establish virtual paths composed of MSs, DMS and HMSs to enable communication to occur between a FS and a HMS. As an example, consider Figure 6 which shows MSs as dots on the plan of one floor of a multi-storey building. The shaded area (SA) is the part of a storey where there is sufficiently low path loss from a MS to a fixed BS site to support communications or where this MS can form a virtual path to the fixed BS where each MS in the virtual path is able to directly signal to SC. An originating hidden MS, MS1 communicates to a fixed BS via the virtual path shown by broken lines in Figure 6. MS4 in the shaded area provides the signalling path to SC for the MSs participating in the virtual path, namely MS1, MS2, MS3 and MS4 and may pass the originating MS's traffic to other repeating MSs outside the building, or directly to a fixed BS, depending on the instructions from SC. In general, the virtual paths will be in three-dimensions, rather than the exemplary two-dimensional plane of the Figure. SC is able to establish and modify virtual paths involving MSs

with whom it cannot directly signal to because of excessively high path loss and/or interference values. In Figure 6, MS4 is a DMS, while MS1, MS2 and MS3 are hidden MSs. The DMS is in effect a surrogate fixed BS. It is also a MS that may be involved in virtual paths composed of other MSs that are able to signal directly to the fixed BSs. By the use of DMS, SC is able to exercise its authority over hidden MSs in regard to network access, paging, general supervision, establishment of virtual paths and their modification, and so on.

As a further example, consider Figure 7 where MS_1 wishes to communicate, and therefore has to connect to a FS. In Figure 7 the X symbols signify mobile stations and the arrows through the X symbols indicate the directions of movement of the mobile stations. SC identifies the virtual path with radio links MS_1 to MS_2, MS_2 to MS_3, MS_3 to MS_4, MS_4 to MS_5, MS_5 to MS_6 and MS_6 to FS. SC sets up a two-way communication between MS_1 and FS using the above virtual path. SC also notes the direction, speed and acceleration of each MS in the path. Suppose MS_3 is a fast moving MS in the direction shown by its arrow. At some point SC will find an alternative path not involving MS_3, such as using the links MS_2 to MS_7, MS_7 to MS_8, MS_8 to MS_9 and MS_9 to MS_4. The other links in the original virtual path are unchanged. Notice also that if MS_1 needs to communicate at a high bit rate it will need more than one path. For example, in Figure 7 the original virtual path could be used (assuming MS_3 is not travelling too fast) and an additional path composed of links MS_1 to MS_{10}, MS_{10} to MS_7, MS_7 to MS_8, MS_8 to MS_9, MS_9 to MS_{11}, MS_{11} to MS_{12}, MS_{12} to MS_{13} and MS_{13} to FS.

When SC employs a radio planning tool that calculates path loss in three-dimensions, for example, the proprietary NP WorkPlace radio planning tool of Multiple Access Communications Ltd, then on receiving from one

or more DMS's reports of received signal levels from beacon signals transmitted from the fixed BS sites, SC is able to deduce where the DMS or DMSs are, and where the hidden MSs are located. Identification of where hidden MSs reside, via knowledge of where the hidden MSs are located along a virtual path, enables SC to notify emergency authorities of the location of a hidden MS whose user seeks the aid of an emergency service. Knowledge of a hidden MS's location may also be used to navigate this MS to a required destination.

The second aspect of the invention is applicable not only to the use of terrestrial base stations but also to systems which create terrestrial cells by means of satellites or aerial platforms. An aerial platform may be an airship or an aeroplane, for example. One of the problems with such systems is that the satellites/aerial platforms and responding MSs are power limited in that it is difficult to communicate with MSs in buildings. Using our hidden MS concept, providing a MS has a relaying capability, then virtual paths at lower power can provide signalling and traffic flow from hidden MSs to DMS. The DMS is a MS that is the same as the hidden MS, except it is sufficiently exposed to conduct communications to a satellite or aerial platform for the hidden MSs.

CLAIMS

1. A radio communication network comprising a plurality of relatively closely spaced-apart mobile stations (MSs), each mobile station MS comprising mobile station radio transmitter means and mobile station radio receiver means, at least some of the mobile stations being arranged to act as controlled repeaters to relay an incoming traffic signal to a nearby mobile station MS or mobile stations MSs, and being controlled by a central system control means SC able to communicate with each mobile station MS, characterised in that the central control means has map data stored therein, or available thereto, the map data providing two-dimensional, or three-dimensional, information on the physical layout and local transmission characteristics of the region in which the mobile stations are located, the central system control SC means being so arranged as to utilise information gained by monitoring the power required to perform a signal exchange (handshake) between adjacent mobile stations MSs and information from the map data, to provide an estimate of the actual positions of the mobile stations MSs.

2. A radio communication network as claimed in claim 1 in which each MS exchanges signals at relatively low power with other MSs which are in close proximity, notes the transmitted and received signal power used in these exchanges, obtains from the neighbouring MSs their identities, performs these procedures periodically, and signals at high power to the fixed base station BS sites in the network a report on the transmitted and received powers used in the exchanges with neighbouring MSs as well as the identities of these MSs, the fixed BS sites conveying this information to system control means SC.

3. A radio communication network as claimed in claim 2 in which initially SC uses only the identities in the reports, and estimates the position of the MSs that are so close to a BS that in making the signalling exchanges they not only interacted with other MSs, but also with a BS, and next the locations of the MSs that exchanged signals with the MSs close to the BS, but not with the BS, are estimated based on their identities, and then the location of the MSs a little further away are considered until an estimate of substantially all MS positions are formed, these locations being estimated substantially on the identity information of the report.

4. A radio communication network as claimed in claim 3 in which SC next employs an algorithm of the kind used in radio planning tools for siting BSs, the algorithm being configured to compute the path losses from a site as a function of distance in all directions from the site, by reference to said stored map data, said path losses being computed for each MS, and at each epoch, *T*, thereby to provide a set of measured path loss values from each MS to its neighbours.

5. A radio communication network as claimed in claim 4 in which for each MS, SC next re-estimates the positions of the neighbouring MSs such that the measured path loss values, and the predicted path loss values that are a function of map data, substantially coincide.

6. A radio communication network comprising a plurality of relatively closely spaced-apart mobile stations, each mobile station comprising mobile station radio transmitter means and mobile station radio receiver means, at least some of the mobile stations being arranged to act as controlled repeaters to relay an incoming traffic signal to a nearby mobile station or mobile stations, and being controlled by a central control means able to communicate with each mobile station,

characterised in that the central control means is so arranged as to identify any 'hidden' MSs with which the central control means cannot directly signal due to excessively high path loss values and/or interference levels, and to identify any MS positioned adjacent to the hidden MS, which may be termed for convenience a 'distributing MS' (DMS), in a position so as to be capable of communicating with the hidden MS, the central control means then providing signals to the hidden MS by way of the distributing MS (DMS).

7. A radio communication network as claimed in claim 6 comprising a three-dimensional radio planning tool, SC being arranged to utilise reports from DMSs on the received signal levels from beacon signals transmitted from the fixed BS sites, or on the received signalling levels from fixed BS sites if they are transmitted at a constant power, to deduce where the DMSs are located, SC utilising reports from the DMSs to predict where the hidden MSs are located.

8. A radio communication network as claimed in claim 6 in which terrestrial cells are provided by a satellite or an aerial platform.

9. A radio communication network substantially as described with reference to Figures 2 to 7.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4L (LDRRS, LDRRX, LDSL)

Int Cl (Ed.7): H04B 7/15, 7/155; H04Q 7/38

Other: Online: WPI, EDOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB2291564 A (NEC)	
A	WPI Abstract Accession No. 98-070120/199807	

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